ENHANCEMENT OF HEAT TRANSFER BY USING NANOFLUIDS IN A HEAT EXCHANGER

[1]Arun Kumar Tiwari
[1]Department of Mechanical Engineering, Institute of Engineering & Technology, GLA University, Mathura, 281004, India
Email: [1]arun_tiwari25@yahoo.co.in

Abstract—
In the present work attempts have been made to theoretically investigate the performance characteristics of hot water-based nanofluid containing Al_2O_3 nanofluid and water as a cold fluid which cross a rectangular arrangement of tubes in a shell and tubes heat exchanger. The hot nanofluid flow in tube side and water as cold fluid flows on shell side. The results show the effectiveness and cooling capacity increases by a considerable amount, while the overall heat transfer coefficient increases even further at higher nanoparticle concentrations. It was also found that the performance of heat exchanger increases appreciably due to use of Al2O3 nanofluid.

Keywords: Shell and tube heat exchanger, Nanofluid, Heat transfer, Performance

I. INTRODUCTION

Heat exchangers play an increasingly important role in the field of energy conservation. The need for better efficient heat exchanging system is required for new technological and industrial development. Therefore, the scientific attention is concentrating both on improving the equipment design and on enhancing the thermal potential of the working fluid. A substantial reduction in energy consumption could be made possible by improving the performance of heat exchanger systems. Due to inadequacy of conventional fuel, optimization in energy consumption in various industrial processes become very important [1].Heat transfer rate in a heat exchanger are dependent on the thermo physical properties of the fluids participating in the heat exchanger, the material of the heat exchanger and also the areas of the surfaces participating in the process [2].Numerous investigations have been made for decades to enhance heat transfer [3-7], minimize heat exchanger size and increase efficacy of fuel and energy.

The increase in heat transfer rate can be affected in heat exchangers in two ways. Firstly, a change in geometrical configuration of the heat exchanger can change the heat transfer rate. The second method is to change the properties of the fluids participating in heat transfer and the material of the heat exchanger. Here, the second method has been explored by using nanofluids as one of the participating fluids in the heat exchanger. Nanofluids are the new generation heat transfer fluids for various industrial and automotive applications because of their excellent thermal performance and the word was which was coined at Argonne National Laboratory of USA by Choi in 1995 [8], which showed that the conventional liquid thermal performance could be remarkably improved using nanoparticles. Nanofluids can be used for a wide variety of engineering applications like transportation, electronics, medical, food, defense, nuclear, space, and manufacturing of many types [9]. Magnetic nanoparticles in bio-fluids can be used for medical applications as drug delivery vehicles, providing new cancer treatment technique. Using nanofluids in heat transfer applications will provide a number of potential advantages, such as better long-term stability, miniaturized heat exchangers, improved heat transfer, reduced heat transfer fluid inventory, little penalty in pressure drop, and can have significantly greater thermal conductivity. As a result, these offer an opportunity for engineers to develop highly compact and effective heat transfer equipments.

One of the key feature for heat transfer enhancement is the thermal conductivity, the majority of the studies [10-16] have discussed the thermal conductivity of nanofluids. All experimental results [17-19] have point out the impressive improvement of thermal conductivity by employing nanoparticle. The addition of aluminum oxide particles were reported to enhance the resulting thermal conductivities of base fluids by up to 30% at particle volume fraction of Al_2O_3 of 5% [10, 11], 4% [12] or 3% [13]. A significant improvement has been reported in the thermal conductivity, liquid viscosity and heat transfer coefficient etc., which are key parameters for the efficient functioning of the heat exchanger.

Shell and tube heat exchangers are the most versatile type of heat exchangers that find widespread use in chemical processing, refrigeration, air conditioning, condenser in power generation, water heating, manufacturing and medical applications, and they are proposed for many alternative energy applications including ocean, thermal, and geothermal. These widespread applications can be justified by its large ratios of heat transfer area to volume, great flexibility, reliability and ease manufacturing for a high pressure and flow configurations. Literatures on shell and tube heat exchanger using nanofluids are limited. Farajollahi et al. [20] investigated the heat transfer characteristics of γ- Al_2O_3/water and TiO_2/water nanofluids in a shell and tube heat exchanger experimentally considering water as working fluid. They measured the heat transfer characteristics in a shell and tube heat exchanger under turbulent flow condition at optimum nanoparticle concentrations and showed significant heat transfer enhancement. Khoddamrezaee et al. [21] simulate the characteristics of EG/ Al_2O_3 nanofluid in a shell and tube heat exchanger with rectangular tube arrangement and showed that the effect of shear stress increase can be neglected in compare of unusual heat transfer improvement. Jahar Sarkar [22] theoretically investigated the performance of nanofluid cooled shell and tube heat exchanger (gas cooler) in transcritical CO_2 refrigeration systems and reported that CO_2 cycle improve the gas cooler effectiveness, cooling capacity and COP without penalty of pumping power and also suggested that nanofluid may be used as coolant in shell and tube gas cooler for improvement of the performance of transcritical CO_2 refrigeration cycle.

Very limited information is available on shell and tube heat exchanger using Al_2O_3/water which motivated this investigation. The major goal of the present study, performance analysis of shell and tube heat exchanger with Al_2O_3/water nanofluid has been predicted. The effect of using Al_2O_3 nanofluid with different particle volume concentrations (0.5-4%) are investigated in this study.

II. THERMAL MODELING AND SIMULATION

The Al_2O_3 nanofluid based shell and tube heat exchanger considered in present study..The heat exchanger is counter-flow single pass type, where the cold Al_2O_3nanofluid flows through the tubes and the hot water flows through the shell. As the effect of using Al_2O_3 nanofluid as a cooling medium in shell and tube heat exchanger on the performance improvement is the main aim of the present study. The following assumptions have been made in the analysis:

(1) The heat exchanger is thermally insulated which ensures no heat loss to the surrounding.

(2) Only single-phase heat transfer occurs for nanofluid.

(3) Longitudinal heat conduction is negligible.

(4) The changes in kinetic and potential energies of fluids are negligible.

NANOFLUID SIDE:

Density of Nanofluid, $\rho_{nf} = \varphi.\rho_p + (1-\varphi)\rho_w$

Specific Heat Capacity,

$$Cp_{nf} = \frac{(\varphi.\rho_p.Cp_p + (1-\varphi).\rho_w.Cp_w)}{\rho_{nf}}$$

Thermal Conductivity,

$$k_{nf} = k_w.(1 + 2.72.\varphi + 4.72.\varphi^2)$$

Coefficient of Viscosity,

$$\mu_{nf} = \mu_w\left[1 + 0.15\varphi.e^{\frac{1-\varphi}{\varphi m}}\right]$$

Mass Flow rate, $m_{nf} = Q_{nf}.\rho_{nf}$

Prandtl Number, $Pr_{nf} = \mu_{nf}\frac{Cp_{nf}}{k_{nf}}$

Nusselt No. (Tube Side),

$$Nu_{d,i} = 0.0265.Re_{nf}^{0.8}.Pr_{nf}^{0.3}$$

Outer surface area of each tube, $A_o = 2.\pi.d_o.L$

Hydraulic Diameter, $d_{h,c} = \frac{4.\left(\frac{\pi}{4}\right).(d_s^2 - N.d_o^2)}{\pi.d_s + N.\pi.d_o}$

Mean Velocity in tubes, $u_{nf} = \frac{m_{nf}}{\frac{\pi}{4}d_i^2\rho_{nf}N}$

Reynolds No., $Re_{nf} = u_{nf}\rho_{nf}\frac{d_{h,i}}{\mu_{nf}}$

Friction Factor, $f_{nf} = \frac{0.316}{Re_{nf}^{0.25}}$

WATER SIDE

Effective Diameter (Shell side),

$$d_e = 4.\left[\frac{0.43p_t^2 - \pi(d_o^2/8)}{\pi.(d_o/2)}\right]$$

Mass flow rate along tubes (Shell Side),

$$G_b = \frac{m_w}{\frac{\pi}{4}.(f_b.d_s^2 - f_b.N.d_o^2)}$$

Mass flow rate across tubes (Shell Side),

$$G_c = \frac{m_w}{B.d_s.\left[1 - \frac{d_o}{p_t}\right]}$$

Nusselt No. (Shell Side),

$$Nu_{d,o} = 0.02.\left[d_e.\frac{(G_b.G_c)}{\mu_w}\right].Pr_{nf}^{4}$$

Mean Velocity in Shell, $u_w = \frac{m_w}{\frac{\pi}{4}(d_s^2 - d_o^2 N)\rho_w}$

Reynolds No., $Re_w = G_c\frac{d_e}{\mu_w}$

Friction Factor, $f_w = \frac{0.316}{Re_w^{0.25}}$

Heat Transfer

NANOFLUID SIDE

Heat Transfer Coefficient, $h_{nf} = Nu_{d,i}\frac{k_{nf}}{d_{h,i}}$

Heat Capacity, $C_{nf} = m_{nf}c_{p_{nf}}$

WATER SIDE

Heat Transfer Coefficient, $h_w = Nu_{d,o}\frac{k_w}{d_e}$

Heat Capacity, $C_w = m_w c_{p_w}$

Heat Exchanger Calculations

Overall Heat Transfer Coefficient is given by,

$$\frac{N}{UA_{overall}} = \frac{1}{h_w A_t} + \frac{\ln\frac{d_o}{d_i}}{2\pi k_t 2L} + \frac{1}{h_{nf}A_o}$$

Number of transfer units, $NTU = U * \frac{A_{overall}}{C_{min}}$

Effectiveness

$$\varepsilon_1 = 2.\left[1 + C_r + (1 + C_r^2)^{0.5}.\left(\frac{1 + \exp(-NTU.(1 + C_r^2)^{0.5})}{1 - \exp(-NTU.(1 + C_r^2)^{0.5}}\right)\right]^{-1}$$

$$\varepsilon = \frac{\left(\frac{1-\varepsilon_1 C_r}{1-\varepsilon_1}\right)^n - 1}{\left(\frac{1-\varepsilon_1 C_r}{1-\varepsilon_1}\right)^n - C_r}$$

$$\varepsilon = \left[1 + \frac{1}{n}\left(\frac{1}{\varepsilon_1} - 1\right)\right]^{-1}$$ for Cr=1

$$Q = \varepsilon.C_{min}.(T_{nf,in} - T_{w,in})$$

Outlet temperatures

$$Q = C_{nf}.(T_{nf,in} - T_{nf,out})$$

$$Q = C_w.(T_{w,out} - T_{w,in})$$

Average temperatures

$$T_{nf,avg} = 0.5(T_{nf,in} + T_{nf,out})$$

$$T_{w,avg} = 0.5(T_{w,in} + T_{w,out})$$

III. Results and discussions

The effect of nanoparticle volume fraction on the various performance parameters are as follows:

3.1. Heat transfer coefficient

The heat transfer coefficient in the tubes carrying the Nanofluid increases due to increase in thermal conductivity. There is also increase in the Nusselt number owing to the increase in Reynolds number which causes increase in the heat transfer coefficient. There is 32.7% enhancement in heat transfer coefficient inside the tube due to increase in percentage volume concentration from 0% to 10%.

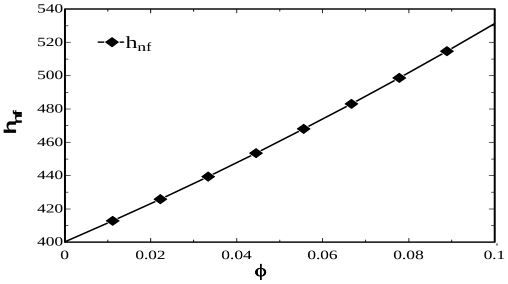

Fig. 1.Heat transfer coefficient versus volume concentration

3.2. Overall heat transfer coefficient

Due to the increase in the heat transfer coefficient inside the tubes, there is an increase in the overall heat transfer coefficient of shell and tube heat exchanger of 30% due to increase in percentage volume concentration from 0% to 10%. This results in an increase in NTU of the heat exchanger.

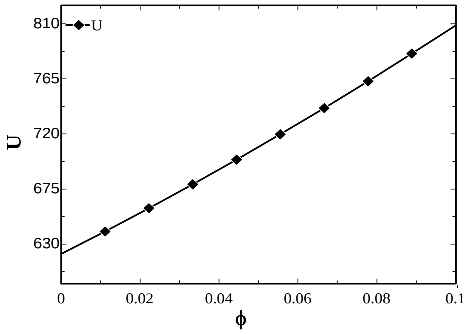

Fig. 2. Overall heat transfer coefficient versus volume concentration

3.3. Effectiveness

The NTU increases with the increase in the volume concentration of nanoparticle. At constant volume flow rate the mass flow rate increases by around 30% but there is drop in specific heat capacity of around 40% .This causes a decrease in the heat capacity by 10%. Thus the ratio between the minimum and maximum heat capacities of the fluid decreases by around 10%. The result is an ultimate increase in the effectiveness of the heat exchanger. The effectiveness of heat exchanger increases by almost 31.3% due to increase in percentage volume concentration from 0% to 10%.

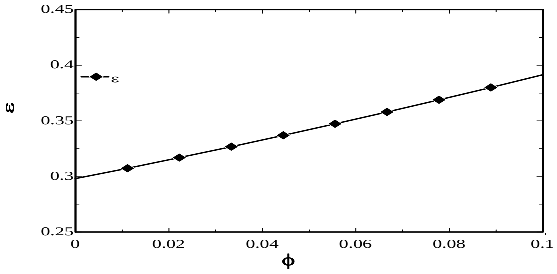

Fig. 3 Effectiveness versus volume concentration

3.4. Cooling capacity

The cooling capacity of the heat exchanger increases due to the increase in the overall heat transfer capacity as well as effectiveness but there is some decrease in the capacity due to the decrease in the specific heat capacity of the Nanofluid. There is 18.16% increase in the cooling capacity of the heat exchanger due to increase in percentage volume concentration from 0% to 10%.

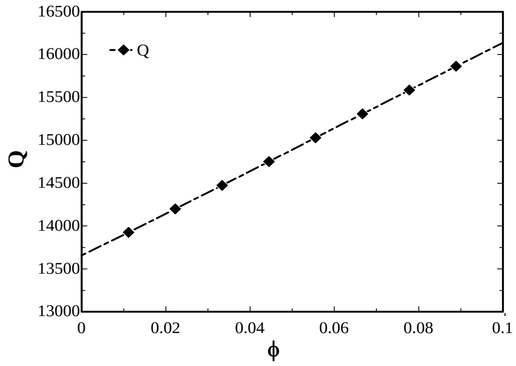

Fig. 4. Cooling capacity versus volume concentration

3.5. Water pressure drop

The pressure drop decreases with increase in the volume concentration of the nanoparticles. This is due to decrease in density of water with increase in average water temperature .The pressure drop on shell side decreases by 0.89% due to increase in percentage volume concentration from 0% to 10%.

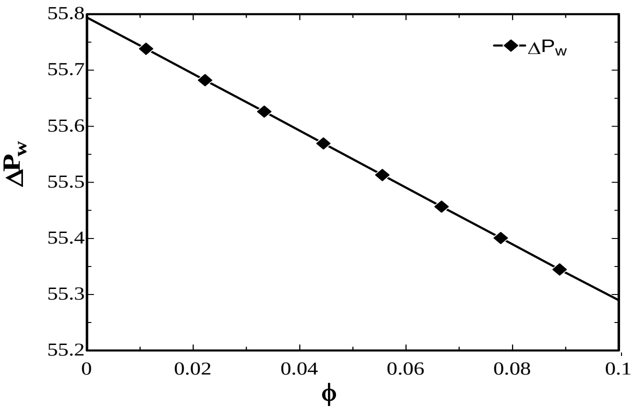

Fig. 5.Pressure drop of water versus volume concentration

The above potentials provided the thrust necessary to begin research in nanofluids, with the expectation that these fluids will play an important role in developing the next generation of cooling technology [25-28].

IV Conclusions

An investigation was carried out to study the performance analysis of shell and tube heat exchanger using Al_2O_3/water nanofluid mathematically. From the results of the present study, it was found out that the effectiveness increases by 31.34%, the overall heat transfer coefficient increases by 30%, the cooling capacity increases by 18.16% due to increase in percentage volume concentration from 0% to 10%.Thus, there is an overall improvement in the performance of the shell and tube heat exchanger due to the use of alumina nanofluid. Thus, use of nanofluid is favorable in case of shell and tube heat exchanger

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